Access Tuition

A-Level Physics

Time Dilation

Mark Scheme

Time available: 42 minutes
Marks available: 31 marks

Mark schemes

1. (a) (for Proper time, t_0 = 31,536,000 s / 365 days)
Dilated time, t = 31,561,259 s ✓

Time dilation is 25,259 s / 421 minutes / 7.0 hours / 0.29 days ✓

The recorded time will be longer (as predicted) ✓
The recorded time will be less than several days longer (as predicted) ✓

Accept answers in other units (e.g. 365.3 days)

Accept an answer of 31582876 seconds / 365.5 days where a proper time of 365.25 days has been used.

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(b) Theory of Special Relativity requires no acceleration ✓

(The spacecraft/frame of reference is) accelerating ✓

Alternative answer:

Theory of Special Relativity requires inertial reference frame ✓

(The spacecraft/frame of reference is) not an inertial reference frame ✓

Accept change in direction / speed / velocity as alternatives for accelerating.

2

[6]

2. (i) time taken $\left(\frac{distance}{speed} = \frac{34}{0.95 \times 3.0 \times 10^8}\right) = 1.1(9) \times 10^7$ s **(1)**

(ii) use of $t = \frac{t_0}{(1 - v^2/c^2)^{1/2}}$ where t_0 = 18 ns

and t is the half-life in the detectors' frame of reference **(1)**

$$\therefore\ t = \frac{18 \times 10^{-9}}{(1 - 0.95^2)^{1/2}} = 57(.6) \times 10^{-9} \text{ s (1)}$$

time taken for π meson to pass from one detector to the other
= 2 half-lives (approx) (in the detectors' frame of reference) **(1)**
2 half-lives correspond to a reduction to 25%,
so 75% of the π mesons passing the first detector
do not reach the second detector **(1)**

alternatives for first 3 marks in (ii)

1. use of $t = \frac{t_0}{\sqrt{(1 - v^2 / c^2}}$, where t_0 = 18 ns

$= \frac{18}{(1 - 0.95^2)^{1/2}}$ = 57.6(ns)
journey time in detector frame (= $2t$) = 2 × 57.6ns (≈ 2 half-lives)

2. use of t = $\frac{t_0}{\sqrt{(1 - v^2 / c^2}}$ where t = 119 ns

= journey time in detector frame

$t_0 = 119\sqrt{1 - 0.95^2}$ =37ns
journey time in rest frame = 2 × 18 ns (2 half-lives)

[5]

3. (a) Newton's laws obeyed in an inertial frame
[or inertial frames move at constant velocity relative to each other] **(1)**
suitable example (e.g. object moving at constant velocity) **(1)**

2

(b) (i) (use of $t = t_0\left(1 - \frac{v^2}{c^2}\right)^{-1/2}$ gives) t_0 = 18 (ns) **(1)**

$t = 18 \times 10^{-9}\left(1 - \frac{(0.995c)^2}{c^2}\right)^{-1/2}$ **(1)**

$= 1.8 \times 10^{-7}$ s **(1)**

(ii) time taken $\left(= \frac{\text{distance}}{\text{speed}}\right) = \left(\frac{108}{0.995 \times 3.0 \times 10^8}\right) = 3.6 \times 10^{-7}$ s **(1)**

time taken = 2 half-lives, which is time to decrease to 25% intensity **(1)**

[alternative scheme: (use of $l = l_0\left(1 - \frac{v^2}{c^2}\right)^{1/2}$ gives) l_0 = 108 (m)

$l = 108\left(1 - \frac{(0.995c)^2}{c_2}\right)^{1/2}$ = 10.8 m **(1)**

time taken $\left(= \frac{10.8}{0.995c}\right) = 3.6 \times 10^{-8}$ s

= 2 half-lives, which is time to decrease to 25% intensity **(1)**]

5

[7]

4. (i) $v\left(=\frac{45}{152\times10^{-9}}\right)$ = 2.96 × 10^8 m s^{-1} **(1)**

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(ii) t = 152 ns **(1)**

$t_0\left[=152\left(1-\frac{v^2}{c^2}\right)^{1/2}\right]=152\left(1-\left(\frac{2.96}{3.00}\right)^2\right)^{1/2}$ **(1)**

= 25 ns **(1)**

2
QWC 2

[4]

5. (a) (i) the same or constant **(1)**
regardless of the speed of the observer or source **(1)**

(ii) physical laws have the same form in all frames **(1)**

(3)

(b) (i) $T_{\frac{1}{2}}$ or beams of mesons $=8.6\text{ ns}\times\left(1-\frac{v^2}{c^2}\right)^{-\frac{1}{2}}$ **(1)**

= 8.6 × $(1 - 0.95^2)^{-\frac{1}{2}}$ = 27.5 ns **(1)**

(ii) beam reduces to 25% in 2 half-lives **(1)**
v(= 0.95 c) = 2.85 × 10^8 m s^{-1} **(1)**
distance = 2 × 27.5 ns × 2.85 × 10^8 m s^{-1} **(1)**
= 15.6 m **(1)**

(6)

[9]